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Research Note

# Accuracy of Meteorological Data Obtained by Tracking the ROBIN With MPS-19 Radar

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## Abstract

A sample of 32 ARCAS-ROBIN rocket soundings that were tracked simultaneously by FPS-16 and MPS-19 radars was examined to determine the accuracy of meteorological data obtained from the less accurate radar, the MPS-19. The root-mean-square error in winds determined by the MPS-19 increased with altitude in a reciprocal relationship from 5 mps at 30 km to 45 mps at 70 km; it was less than 10 mps at all levels below 55 km. No evaluation of the accuracy of thermodynamic data was possible. Any such data obtained from an MPS-19 track will be rejected under the criteria of the existing data reduction program as being from a target that failed to inflate.

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# Accuracy of Meteorological Data Obtained by Tracking the ROBIN with MPS-19 Radar

## 1. INTRODUCTION

Between 24 July and 24 August 1962, tests were made at Eglin AFB, Florida, using ROBIN targets which had been chemically or mechanically modified to determine what effects the alterations had on the ROBIN performance. Some of the balloons were tracked by FPS-16 and MPS-19 radar simultaneously. During the course of the flights, meteorological data were gathered.

Since this information existed, a comparison of the two radar trackings was made in order to determine the error which would result in using the MPS-19 when more accurate radar (FPS-16) was not available.

The comparison is based on 32 soundings for altitudes ranging from 70 to 30 km. The bulk of the report is concerned with wind data which was available for every sounding. The thermodynamic data (density and derived pressure and temperature) was also studied. However, no useful results were obtained because of the limited number of acceptable soundings.

## 2. INSTRUMENTATION

The standard ROBIN (ROcket Balloon INstrumentation) targets are the 1/2-mil mylar, 1-meter spherical balloons developed as a payload for Arcas sounding

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rockets. Upon ejection from the rockets, the spheres are inflated by vaporization of the enclosed isopentane capsule. The falling ROBINS are tracked by one radar set of each type and space-position data in terms of azimuth, elevation, and range is obtained. This information is then reduced (see Reference 1 for a detailed method of data reduction) to the necessary meteorological data (winds, pressure, temperature and density).

The accuracies of the radar used in this experiment are given by the Air Proving Ground Test Center Manual[2] as:

| | Range | Azimuth and Elevation |
|---|---|---|
| FPS-16 | 5 yds | 0.1 mil |
| MPS-19 | 25 yds | 2.0 mil |

(one mil = 1/6400 of a circle = 0.05625 degree).

These estimates of the RMS errors for the FPS-16 agree substantially with those used by Leviton[3] and Engler[1] and are not greatly different than the values used by Scoggins.[4] None of these authors has been concerned with MPS-19 accuracies. Engler quotes values of 1.5 mils and five yards for MSQ radar which should be similar to the MPS. The dissimilarity in quoted values is probably a result of difficulties in determining radar accuracies and types that had been used in the ROBIN development as of the time that Engler wrote.

## 3. DATA

Data used in the comparison of the two types of radar were taken from the 32 soundings at altitudes decreasing from 70 to 30 km. For each height H being studied, the data point on the FPS-16 sounding nearest the desired height was chosen. The actual altitude $Z_f$, the zonal wind $U_f$, and the meridional wind $V_f$ for this data point on the FPS-16 sounding were tabulated and the observation time noted. This observation time was used to enter the MPS-19 sounding for the same ROBIN flight to obtain comparative data $Z_m$, $U_m$ and $V_m$. Because of the difference in the tracking accuracy of the two radars, in general

$$Z_f \neq Z_m$$
$$U_f \neq U_m$$
$$V_f \neq V_m \; .$$

The differences in Z, U and V form the basic data input for analysis. Samplings between 70 and 50 km were taken at 5 km intervals, while those ranging from 50 to 30 km were extracted at 2 km intervals.

In any ROBIN sounding the balloon eventually collapses because external pressure is greater than internal pressure. After this occurs the aerodynamics are unknown so that wind error increases and thermodynamic data cannot be derived. A method of detecting when the balloon has collapsed was devised by Engler[1] and is designated as the $\lambda$ (lambda) check. The 32 soundings were divided into two groups on the basis of failure above or below 50 km. In Group I, the $\lambda$ check indicated failure below 50 km (interpreted to mean that the balloon was inflated and spherical above this point). In Group II, the $\lambda$ check indicated that the balloon failed above 50 km (interpreted to mean that the balloon was never fully inflated). As was noted, the main purpose of the balloon flights was to test various modifications of the instrument system; and Group II is divided into three classes depending upon the nature of the test. They are as follows:

a. Thin-skinned or standard spheres,
b. Deliberately introduced mechanical changes or malfunctions,
c. Inflations with ammonia ($NH_3$) or ammonia and water ($NH_3 + H_2O$) .

## 4. ANALYSIS

### 4.1 Wind

For each sounding and height level, the altitude, zonal wind speed and meridional wind speed were tabulated for the FPS-16 and MPS-19 and their differences (FPS-MPS) were then calculated. The sum of the squared wind differences was also computed. (All wind speeds in this report are in units of meters per second.)

There were 15 soundings in Group I and 17 in Group II. In each group the data was pooled on the basis of height. The sum of the squares of the altitudes and of the winds, both meridional and zonal, were calculated for each level, and the mean value and the root mean square of each group was computed.

The data was first tested to determine if the primary experimentations of the ROBIN flights had in any way affected the meteorological data gathered. The RMS wind vector differences (FPS - MPS) for each subdivision of Group II and for the Group as a whole were calculated (Table 1) and plotted against height (see Figure 1). Examination of Figure 1 shows that no subdivision differs markedly or consistently with altitude from the over-all group value; hence the conclusion was reached that the wind data had not been affected by the experimentation. Also, on the basis of the graph, an analysis of variance was deemed unnecessary.

A second step was to determine if Group I and Group II varied significantly. If they did not, they could be combined into one group and more easily examined. A graph was plotted of the RMS wind vector differences (FPS - MPS) for each group against the height (Figure 2). By inspection of the graph the groups did not seem

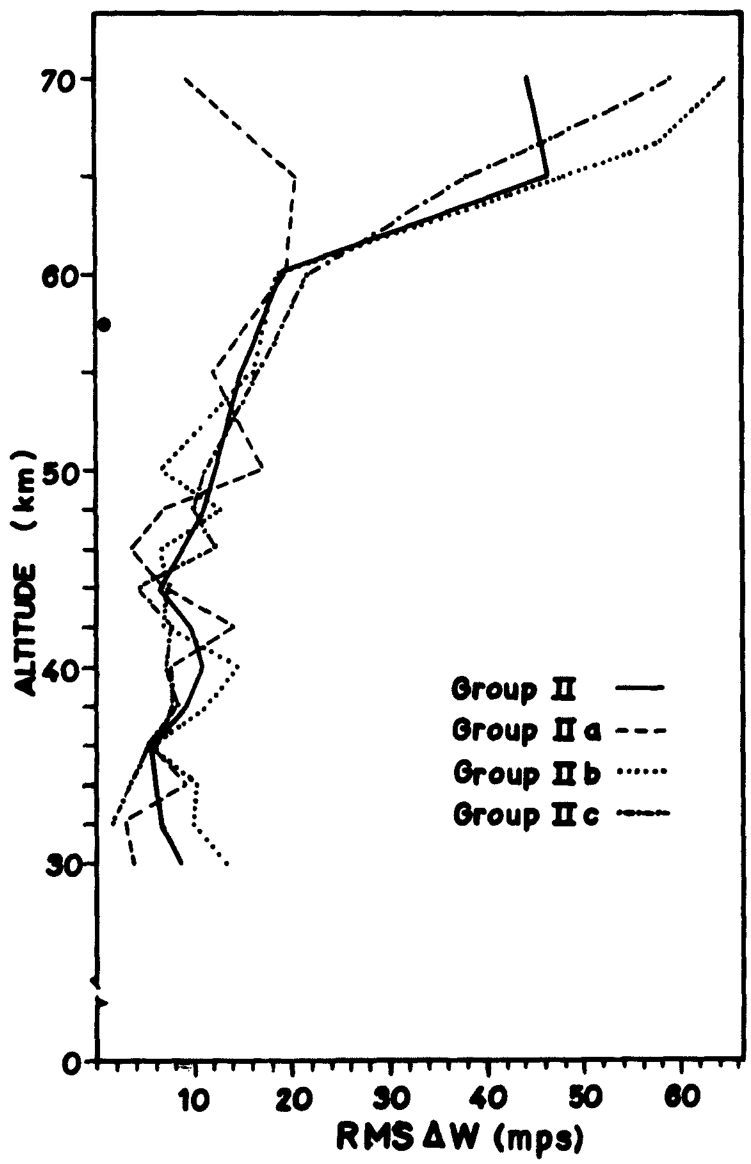


Figure 1. Observed Root-Mean-Square Difference in Winds for Soundings in Group II and its Subdivisions

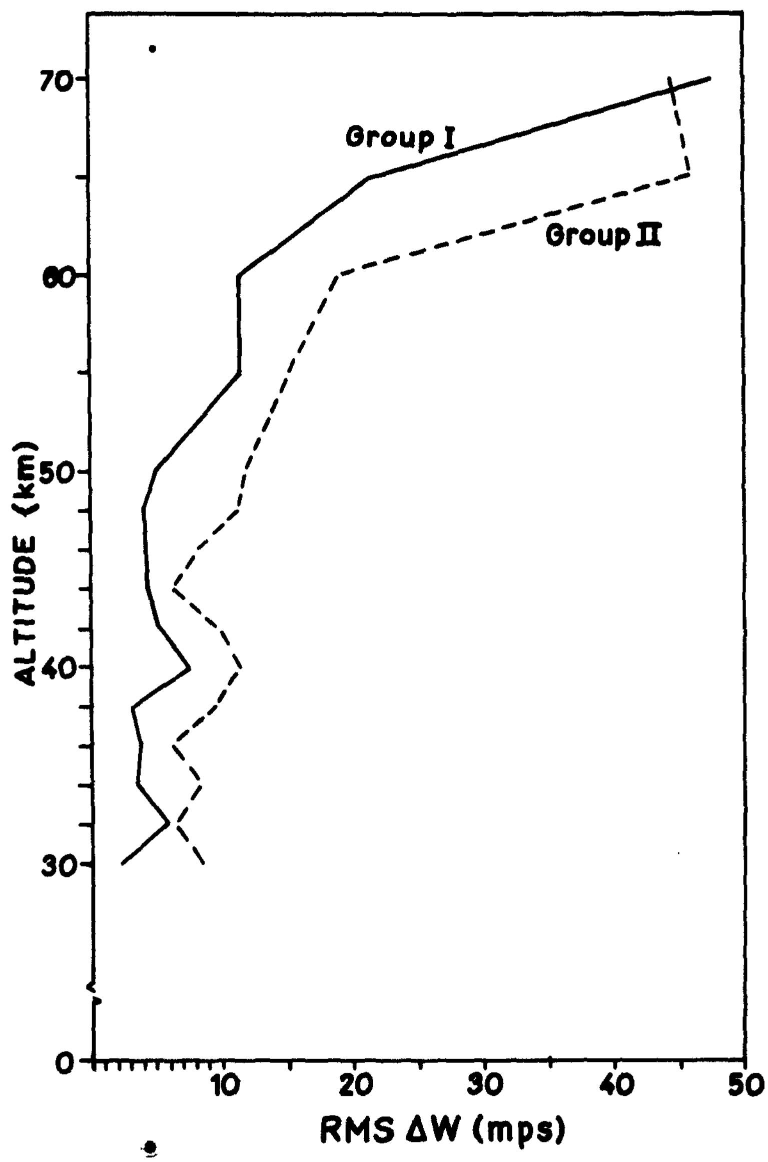


Figure 2. Observed Root-Mean-Square Difference in Winds for Groups I and II

TABLE 1. RMS wind differences (mps) observed for each altitude and subdivision of the sample.

| Height (km) | Group I | Group II a | Group II b | Group II c | Total | Entire Sample |
|---|---|---|---|---|---|---|
| 70 | 47.45 | 8.69 | 65.20 | 59.35 | 44.51 | 45.51 |
| 65 | 21.48 | 20.36 | 58.26 | 38.16 | 45.95 | 38.78 |
| 60 | 11.49 | 19.81 | 18.83 | 18.61 | 19.05 | 16.17 |
| 55 | 11.55 | 11.15 | 16.61 | 15.84 | 15.17 | 13.66 |
| 50 | 4.90 | 17.42 | 6.37 | 11.23 | 11.92 | 9.62 |
| 48 | 4.10 | 6.47 | 13.01 | 9.94 | 11.59 | 8.51 |
| 46 | 4.30 | 3.75 | 6.57 | 12.34 | 8.36 | 6.94 |
| 44 | 4.56 | 7.04 | 7.13 | 4.82 | 6.47 | 5.70 |
| 42 | 5.05 | 14.11 | 7.28 | 8.05 | 9.97 | 8.04 |
| 40 | 7.88 | 7.75 | 14.51 | 7.67 | 11.20 | 9.79 |
| 38 | 3.12 | 7.92 | 11.62 | 8.58 | 9.62 | 7.05 |
| 36 | 3.65 | 5.94 | 5.81 | 5.80 | 6.46 | 4.84 |
| 34 | 3.49 | 9.40 | 10.18 | 7.80 | 7.89 | 5.86 |
| 32 | 5.68 | 3.20 | 10.10 | 2.88 | 6.56 | 6.08 |
| 30 | 4.38 | 4.04 | 13.62 | --- | 8.53 | 6.49 |

to vary greatly, however, the variation was consistent, Group II having larger differences than Group I at all heights. An analysis of variance was made at 9 heights 4 to 5 km apart. The results are shown in Table 2, from which it is concluded that there was a definite difference between the groups at the 5% level and between the individual heights at the 0.1% level of significance.

In attempting to describe the behavior of the vector wind differences with altitude, the deviation between radars in reported heights was taken into account. To do this, a multiple correlation was performed on Group I, relating RMS $\Delta Z$, $H$, and $H^2$. Results of an analysis of variance (Table 3) showed $\Delta Z$ was not significant. Group II appeared to be very similar to Group I and, since the effect of $\Delta Z$ in Group I was so far from being significant, it was assumed to be insignificant in Group II.

This eliminated $\Delta Z$ from further consideration. The next step was to compute the relation of the RMS $\Delta W$ to $H$ and $H^2$ for each group. Visual inspection of the graph (Figure 2) suggested a quadratic model (RMS $\Delta W = a + bH + cH^2$). This was fit by least squares, yielding the following equations:

Group I: $$\text{RMS } \Delta W = 66.0563 - 3.1630\, H + 0.0395\, H^2 \qquad (1)$$

Group II: $$\text{RMS } \Delta W = 65.7365 - 3.0712\, H + 0.0401\, H^2 \qquad (2)$$

These equations made a highly significant reduction in the variance as is shown by the analysis in Table 4. In spite of the significance, this fit was judged to be unsatisfactory as the estimated minimum values of RMS $\Delta W$ did not occur at the bottom of the profiles as might be expected. By differentiating the model equation and equating it to zero, the height at which the minimum value of RMS $\Delta W$ occurs is

TABLE 2. Analysis of variance of RMS wind differences ($\Delta W$) for groups and heights

| Source | Sum of Squares | Degrees Freedom | Variance | F | Significance Level (%) |
|---|---|---|---|---|---|
| Between Groups | 162.42 | 1 | 162.42 | 5.71 | 5.0 |
| Between Heights | 3247.74 | 8 | 403.97 | 14.28 | 0.1 |
| Residual | 227.38 | 8 | 28.42 | | |
| TOTAL | 3637.54 | 17 | | | |

TABLE 3. Analysis of variance for multiple correlation of RMS wind differences with RMS deviation in actual height and, quadratically, with nominal height

| Source | Sum of Squares | Degrees Freedom | Variance | F | Significance Level (%) |
|---|---|---|---|---|---|
| $\Delta Z$ | 0.24 | 1 | 0.24 | 0.013 | Not signif. |
| H | 1112.15 | 1 | 1112.15 | 60.35 | 0.1 |
| $H^2$ | 552.76 | 1 | 552.76 | 29.99 | 0.1 |
| Residual | 202.75 | 11 | 18.43 | | |
| TOTAL | 1867.90 | 14 | | | |

TABLE 4. Analysis of variance for quadratic regression of RMS $\Delta W$ on height by groups

| Source | Sum of Squares | Degrees Freedom | Variance | F | Significance Level (%) |
|---|---|---|---|---|---|
| Group I | | | | | |
| Conditional | 1599.87 | 2 | 799.94 | 35.81 | 0.1 |
| Residual | 268.03 | 12 | 22.34 | | |
| TOTAL | 1867.90 | 14 | | | |
| Group II | | | | | |
| Conditional | 2076.23 | 2 | 1038.12 | 58.78 | 0.1 |
| Residual | 211.97 | 12 | 17.66 | | |
| TOTAL | 2288.20 | 14 | | | |

given by $H = -b/2c$ . For the fitted equations, this height is 40.03 km in Group I and 38.25 km in Group II.

Other curve types were investigated and plotting of reciprocals (see Figure 3) led to the decision to employ the form $1/\mathrm{RMS}\,\Delta W = a + bH$ . This was fit by least squares to the data for each group separately and to the pooled data for both groups, and the following equations were obtained.

$$\text{Group I:} \quad 1/\mathrm{RMS}\,\Delta W = 0.45620 - 0.00593\ H \tag{3}$$

$$\text{Group II:} \quad 1/\mathrm{RMS}\,\Delta W = 0.23985 - 0.00311\ H \tag{4}$$

$$\text{Combined:} \quad 1/\mathrm{RMS}\,\Delta W = 0.30499 - 0.00404\ H \tag{5}$$

The reduction in variance provided by these equations is shown in Table 5. The F ratios for each group are smaller than for the quadratic equations but the level of significance is still one-tenth percent.

TABLE 5. Analysis of variance for linear regression of reciprocal of RMS wind difference with nominal height by groups and for entire sample.

| Source | Sum of Squares | Degrees Freedom | Variance | F | Significance Level (%) |
|---|---|---|---|---|---|
| Group I | | | | | |
| Conditional | 0.07210 | 1 | 0.07210 | 22.05 | 0.1 |
| Residual | 0.04255 | 13 | 0.00327 | | |
| TOTAL | 0.11465 | 14 | | | |
| Group II | | | | | |
| Conditional | 0.019800 | 1 | 0.01980 | 41.25 | 0.1 |
| Residual | 0.00629 | 13 | 0.00048 | | |
| TOTAL | 0.02609 | 14 | | | |
| Combined | | | | | |
| Conditional | 0.12726 | 1 | 0.12726 | 192.82 | 0.1 |
| Residual | 0.00859 | 13 | 0.00066 | | |
| TOTAL | 0.13585 | 14 | | | |

The quantity that is ultimately desired is the error in wind as determined by the MPS-19 radar. This can be computed from $\overline{\Delta W^2} = E_{16}^{\ 2} + E_{19}^{\ 2}$ , where $E_{16}^{\ 2}$ is the mean square error in wind determined by the FPS-16 and $E_{19}^{\ 2}$ is the mean square error in wind determined by the MPS-19. This assumes that $E_{16}$ and $E_{19}$ are errors independent of each other, that if the FPS-16 radar makes an error in

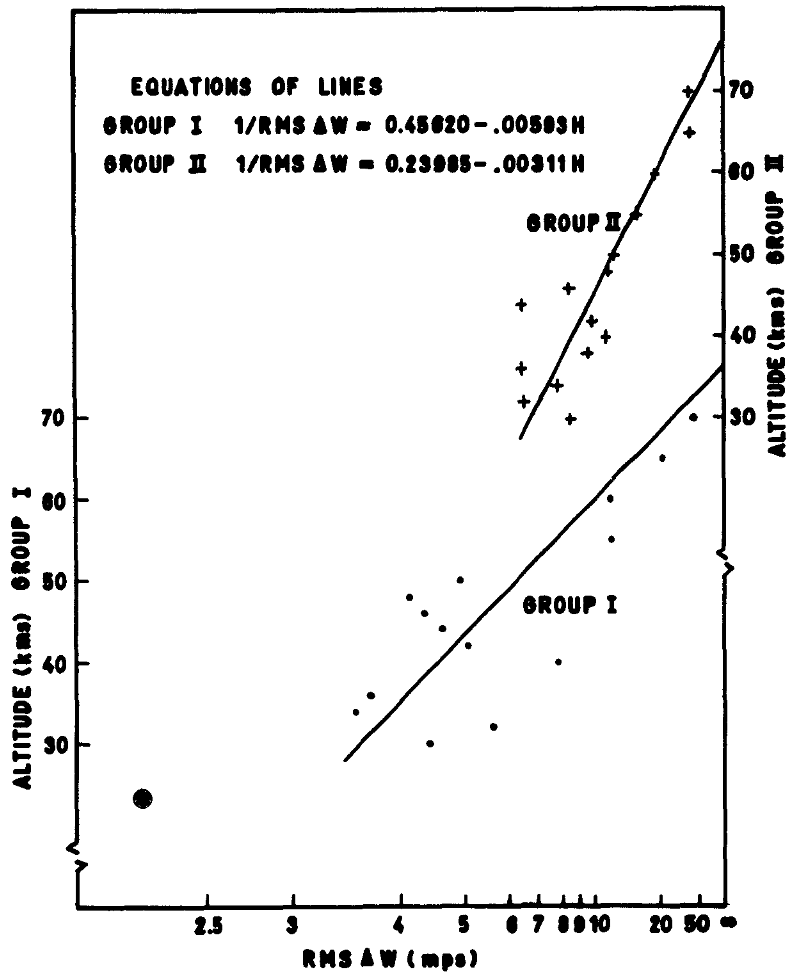


Figure 3. Observed and Fitted Values of Root-Mean-Square Difference in Winds for Groups I and II, Plotted as Reciprocals

determining the target position at a given instant, this error in no way affects the accuracy of the position determined by the MPS-19 at the same instant.

If, as is expected, the MPS-19 error is much larger than the FPS-16 error, the effect of the squared relationship will be that $E_{19}$ will be only slightly smaller than RMS ΔW. Thus the equations for 1/RMS ΔW given above can be taken as descriptions of the maximum possible value of the RMS error in winds determined by the MPS-19. The equation for the combined data provides a general statement while that for Group I describes conditions when inflation occurs and that for Group II describes events when inflation does not occur.

In order to provide a slightly more realistic estimate of $E_{19}$, some estimate of $E_{16}$ is required. The accuracy of wind determination, $E_{16}$, using FPS-16 radar to track a spherical ROBIN has been investigated by Engler[1] and his results have been smoothed by Lenhard and Wright[5] yielding the expression $1/E_{16} = 5.00114 - 0.07051\ H$. This equation is a satisfactory description of the data from which it was derived but does not extrapolate well. It provides somewhat larger estimates for the errors above 65 km than seem reasonable and yields negative values above 70.9 km. It appears to underestimate the errors below 45 km from the practical standpoint since it refers to spherical targets and, in actuality, most inflated ROBINS are no longer spherical after they fall below about 40 km and are probably departing from sphericity for some distance above this level. In this sample, the average height at which the lambda check indicated collapse for the flights in Group I was 45 km.

An estimate of $E_{16}$ that seems reasonable can be obtained by combining information available from this sample with that yielded by previous studies. It is noted that RMS $\Delta W$ at 30 km is larger for Group II than for Group I. This implies that, after they have both been collapsed by external pressure about as much as they can be, the error in winds from an uninflated balloon is greater than the error in wind for an inflated balloon. This relationship is assumed to hold through all altitudes, although not at a constant value, until a height is reached where the normal ambient pressure is insufficient to prevent a balloon from being inflated to nearly spherical shape by the air entrapped in packaging. This altitude is estimated as 76.7 km by solving Equations (3) and (4).

In Table 7 of Reference 5, the error in uninflated balloons is given as 3.85 at 64 km and 2.95 at 43 km. These points yield

$$1/E_{16} = 0.50123 - 0.00377\ H \quad . \tag{6}$$

Equation (6) gives $E_{16} = 4.72$ at 76.7 km where the current sample indicates that all balloons are nearly spherical and yield the same error in wind since RMS $\Delta W$ for Group I equals that for Group II. To obtain an expression for the error resulting from inflated balloons, this point is combined with the values of 2.27 at 65 km and 0.93 at 55 km obtained from Reference 1 and a reciprocal relation fitted by least squares:

$$1/E_{16} = 3.14683 - 0.03921\ H \tag{7}$$

This fit is not especially good − the F-ratio has a probability between 10 and 25 percent of being exceeded if no relationship actually exists. A better fit, or other assumptions, would have little effect on the final results so this equation is accepted.

Expressions can be obtained describing the change of $E_{19}$ with altitude by combining Equations (3) and (7) for inflated targets (Group I) and Equations (4) and (6) for uninflated targets (Group II). They are rather complicated and are not presented here because of their inconvenience in estimating magnitudes of $E_{19}$. Instead, the values of $E_{16}$ and $E_{19}$ have been computed for several altitudes for each group of soundings and are given in Table 6.

TABLE 6. Estimated RMS differences in wind between, and wind errors of, FPS-16 and MPS-19 radars tracking inflated and uninflated ROBIN targets (mps).

| Height (km) | Group I | | | Group II | | | Combined RMS ΔW |
|---|---|---|---|---|---|---|---|
| | RMS ΔW | $E_{16}$ | $E_{19}$ | RMS ΔW | $E_{16}$ | $E_{19}$ | |
| 70 | 24.33 | 2.49 | 24.20 | 45.15 | 4.21 | 44.95 | 45.07 |
| 65 | 14.13 | 1.67 | 14.03 | 26.53 | 3.90 | 26.24 | 23.59 |
| 60 | 9.96 | 1.26 | 9.88 | 18.78 | 3.64 | 18.42 | 15.98 |
| 55 | 7.69 | 1.01 | 7.62 | 14.53 | 3.40 | 14.12 | 12.08 |
| 50 | 6.26 | 0.84 | 6.20 | 11.86 | 3.20 | 11.42 | 9.71 |
| 45 | 5.28 | 0.72 | 5.23 | 10.01 | 3.02 | 9.54 | 8.12 |
| 40 | 4.57 | 0.63 | 4.53 | 8.66 | 2.85 | 8.18 | 6.97 |
| 35 | 4.02 | 0.56 | 3.98 | 7.63 | 2.71 | 7.13 | 6.11 |
| 30 | 3.59 | 0.51 | 3.55 | 6.82 | 2.58 | 6.31 | 5.44 |

Several other methods of estimating $E_{16}$ were tried and discarded on the grounds of internal inconsistencies or contradictory implications resulting from them. None provided drastically different estimates of $E_{19}$, however. It may be noted from Table 6 that the estimates of $E_{19}$ do not differ by as much as 1 meter per second from the values of RMS ΔW . Values of the latter for Equation (5) are included in Table 6 as a general estimate of the accuracy of MPS-19 winds, knowing nothing about the state of the sphere.

Interpretation of the RMS statistic depends upon the assumption that the error being dealt with is random error. To check this a bias analysis was run on the combined data by computing mean values for each level. These values are shown in Table 7. While none are zero, most vector means are smaller than 2 mps and the component means show (for the most part) no systematic behavior in magnitude or algebraic sign. The exceptions are the two highest levels, 70 and 65 km. The dispersion about the bias at these levels differs by less than 5% in the extreme case, and generally by less than 1% when the groups are examined separately. This implies that the differences computed from individual runs tend to have

TABLE 7. Component and vector mean wind differences (mps) for complete sample.

| Height | n | $\Delta U$ | $\Delta V$ | $\sqrt{\Delta U^2 + \Delta V^2}$ |
|---|---|---|---|---|
| 70 | 6 | 11.40 | 16.48 | 20.04 |
| 65 | 21 | 16.92 | 13.43 | 21.60 |
| 60 | 25 | 1.70 | -1.26 | 2.12 |
| 55 | 29 | -0.74 | -1.29 | 1.48 |
| 50 | 31 | 1.03 | -1.87 | 2.14 |
| 48 | 33 | 0.04 | -0.73 | 0.73 |
| 46 | 33 | -0.01 | -0.29 | 0.29 |
| 44 | 34 | 0.77 | 0.53 | 0.93 |
| 42 | 32 | -1.47 | -0.07 | 1.47 |
| 40 | 30 | -1.12 | 0.71 | 1.33 |
| 38 | 29 | 0.18 | -0.40 | 0.44 |
| 36 | 29 | 0.59 | -0.19 | 0.62 |
| 34 | 27 | 1.16 | -1.35 | 1.78 |
| 32 | 25 | 0.98 | -1.06 | 1.45 |
| 30 | 27 | 0.13 | -0.52 | 0.54 |

offsetting algebraic signs, which is the case. The observed deviations from a zero mean can be ascribed to the effects of sampling and the RMS accepted as a measure of random error.

## 4.2 Thermodynamic Parameters

Evaluation of the accuracy of thermodynamic data obtained with MPS-19 tracking was attempted unsuccessfully. Very few points were available for comparison because of the relatively few soundings (15) which could be regarded as made by rigid spheres and because of the limited altitude range for which coincident MPS-19 and FPS-16 data points existed. These soundings and ranges are indicated in Table 8.

The few available points were processed, nevertheless, but the results were meaningless, as expected. At some altitudes the mean square error in parameters determined by the MPS-19 turned out to be negative. In other cases the MPS-19 error was estimated to be equal to or even an order of magnitude smaller than the FPS-16 error. The combination of a limited range of altitudes with excessive variability due to a small sample rendered the rational estimation of the MPS-19 accuracies impossible.

From the practical standpoint, applying the criteria for a rigid sphere pertinent to the FPS-16 tracking to data obtained with MPS-19 would reject all but two of the soundings yielding valid thermodynamic data. As can be seen from Table 8, the MPS-19 data indicates failure above 50 km on all runs except 8 and 21. This would be interpreted to mean that targets had never been fully inflated on any but two flights, each of which provided data for less than 1 km of altitude. The obvious

TABLE 8. Altitude (meters) of top and bottom of thermodynamic data obtained from inflated ROBIN soundings as determined by FPS-16 and MPS-19 radars

| Run | Top | | Bottom | |
|---|---|---|---|---|
| | FPS-16 | MPS-19 | FPS-16 | MPS-19 |
| 8 | 48045 | 49974 | 46752 | 49278 |
| 10 | 57198 | 56575 | 44817 | 52715 |
| 13 | 64099 | 64147 | 46856 | 61151 |
| 14 | 66362 | 66516 | 42988 | 63361 |
| 17 | 61261 | 60895 | 42010 | 56893 |
| 19 | 59140 | 59221 | 45844 | 57814 |
| 21 | 45320 | 44459 | 41881 | 43885 |
| 24 | 66257 | 66208 | 43480 | 64816 |
| 25 | 66734 | 66685 | 42706 | 54167 |
| 27 | 68952 | 68711 | 49209 | 65882 |
| 30 | 66662 | 66581 | 50256 | 53991 |
| 33 | 67049 | 66644 | 46020 | 64532 |
| 37 | 67259 | 67277 | 46125 | 52834 |
| 50 | 61122 | 60324 | 46646 | 58438 |
| 51 | 69569 | 69504 | 45562 | 67635 |

inference is that to obtain thermodynamic data from an MPS-19 track, regardless of the accuracy, the criteria for determining when the ROBIN is a rigid sphere must be changed to suit the radar.

## 5. SUMMARY

The RMS error in winds obtained from tracking a falling ROBIN with MPS-19 radar increases from 4 - 6 mps at 30 km to 24 - 45 mps at 70 km. The reciprocal of the error decreases linearly with altitude. The larger errors apply to targets that were not inflated, the smaller errors to inflated targets. Uninflated targets yield winds with about twice the error of inflated targets. The RMS error is less than 10 mps below 50 km for uninflated targets.

Thermodynamic data cannot be obtained from an MPS-19 radar and the current data reduction program as the lambda check will reject targets above 50 km, thus indicating that no valid determination of density, temperature or pressure can be made. This will occur on nearly all soundings, including those that would have provided valid data with FPS-16 tracking. Because this occurred in the sample used in this study, no rational estimate of errors of thermodynamic data from an MPS-19 could be made.

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